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Using Machine Learning Methods to Predict Similarity of Striations on Bullet Lands

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Using Machine Learning Methods to Predict Similarity of Striations on Bullet Lands

Disciplines

Forensic Science and Technology

Comments

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Using Machine Learning Methods to Predict Similarity of Striations on Bullet Lands

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ISU CSAFE bullet team,
Alicia Carriquiry, Susan VanderPlas

Outline

- ★ Background, Data, and access to it
- ★ Feature extraction: from raw data to information
- ★ Results from Matching



Over-arching Objective

★ **Same Source Problem:** were two bullets fired through the same gun barrel?

★ **Currently:** Firearms and Toolmarks Examiner use visual inspection under a comparison microscope: *subject bias, error rates?*

“much forensic evidence – including, for example, bite marks and firearm and toolmark identification is introduced in criminal trials without any meaningful scientific validation, determination of error rates, or reliability testing.” (National Research Council 2009)

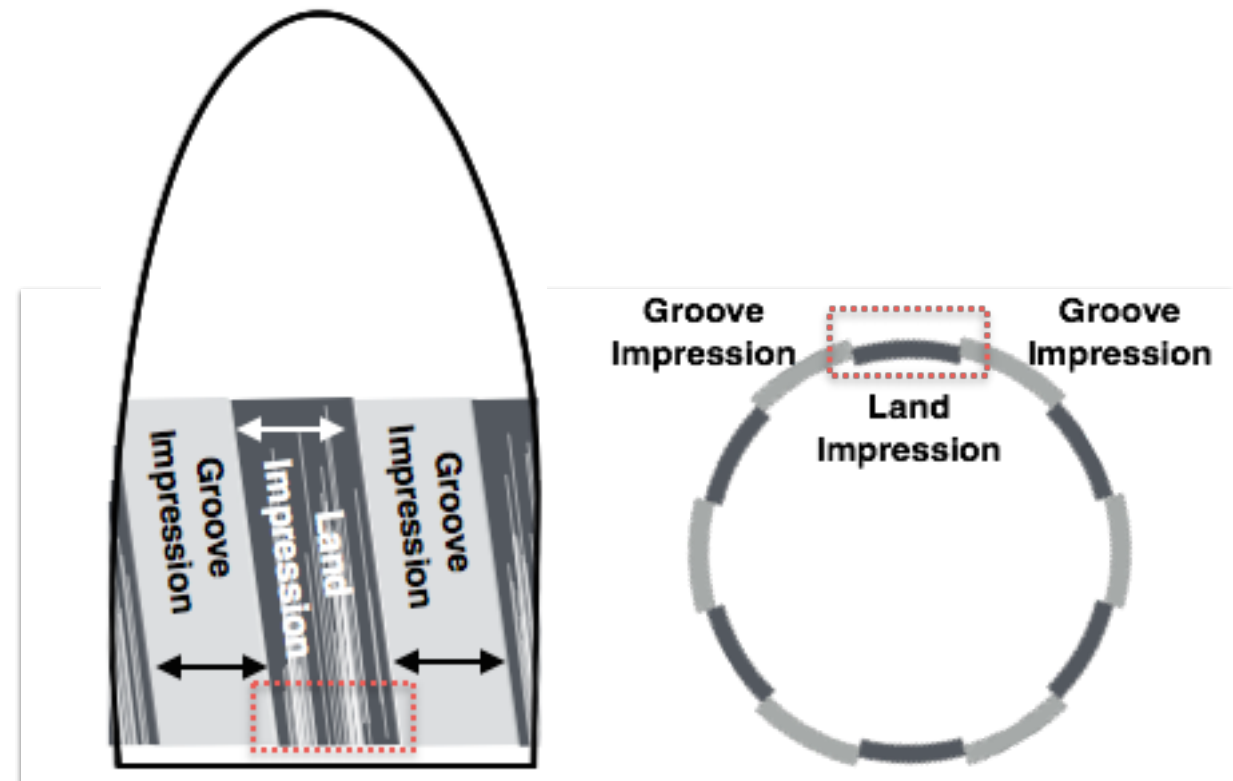
★ **Goals:** (1) determine *score* as objective measure for the match, (2) establish error rates



Barrel rifling and striae



- ★ Barrel rifling introduces land and groove impressions on bullets
- ★ micro-imperfections introduce striation marks



Data Sources

- ★ NIST Ballistics Toolmarks Research Database:
<https://tsapps.nist.gov/NRBTD>
- ★ 2d images and 3d scans of cartridge cases (firing pin and breech face impressions) and bullets
(Land engraved areas)
- ★ Relatively little data on bullets, larger number of
cartridge cases

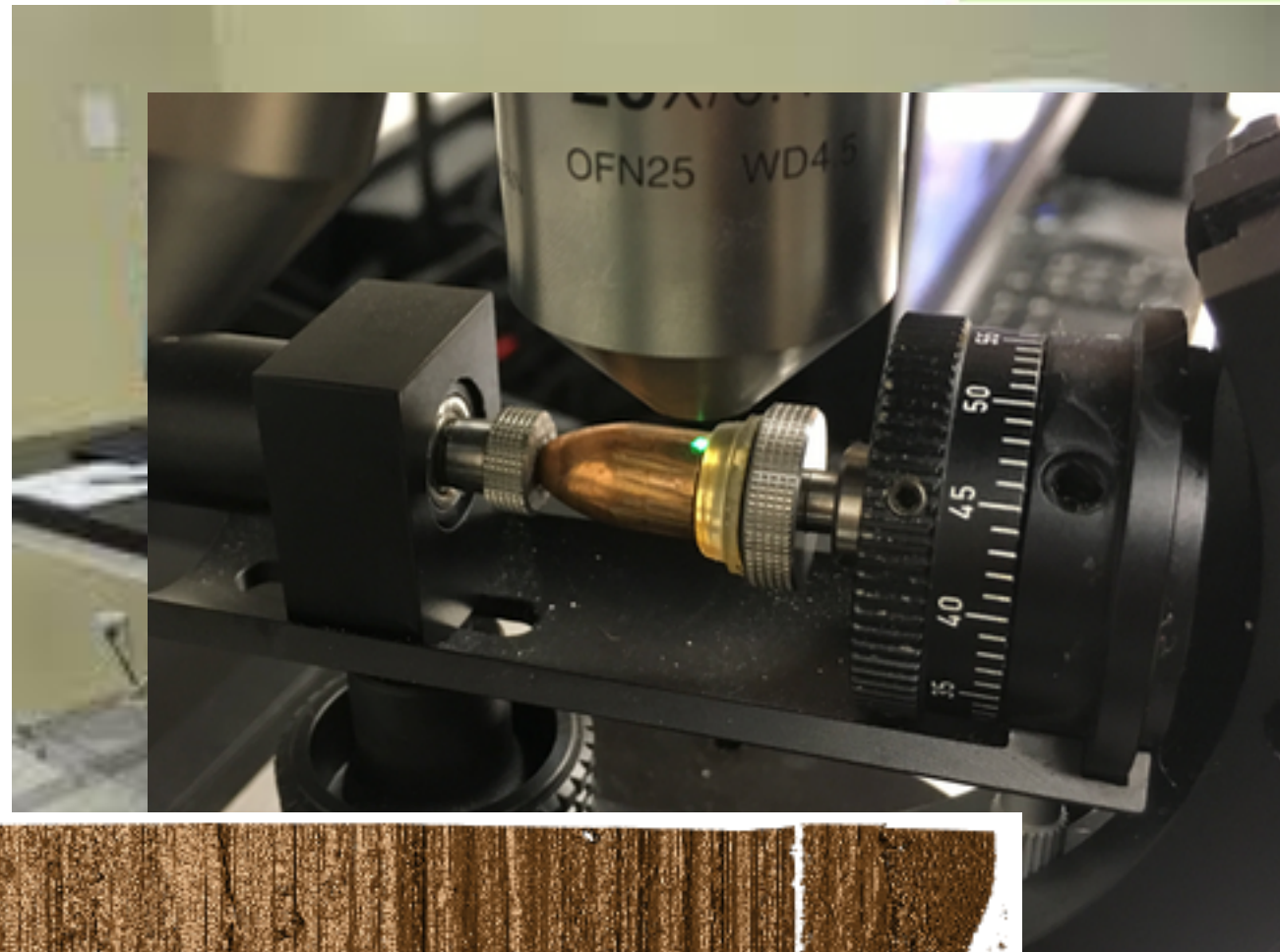
Microscope Facility

Roy J. Carver High Resolution Microscopy Facility

Two Sensofar Confocal
Light Microscopes

Four undergraduates
scanning bullet lands

3d topographic images:
height measurements on
x-y grid



Data from CL Microscope

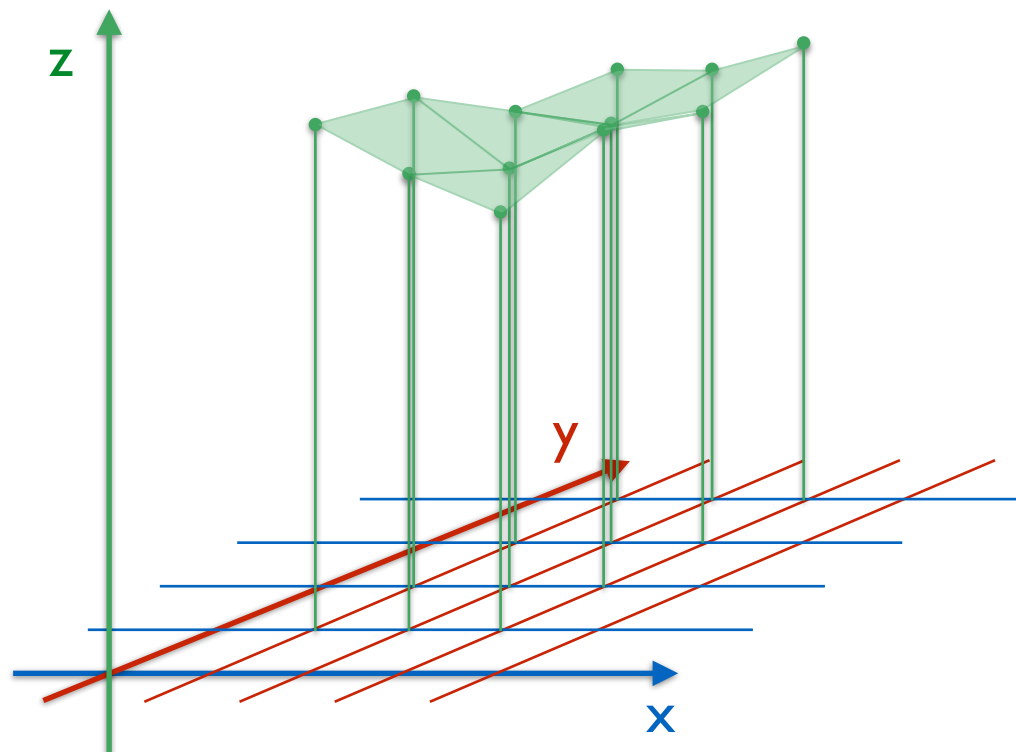
x-y-z files

Data captured on grid of

$0.645 \mu m \times 0.645 \mu m$

Total captured area for
each land

$\sim 2.2 mm \times 0.6 mm$



x - y - z file

x	y	z
18.705	0.000	-25.221138
19.350	0.000	-25.253155
19.995	0.000	-25.335022
20.640	0.000	-25.418171
21.285	0.000	-25.477917
21.930	0.000	-25.541687
22.575	0.000	-25.673903
23.220	0.000	-25.966341
23.865	0.000	-40.070286
24.510	0.000	-40.407612
25.155	0.000	-40.587063
25.800	0.000	-33.437973
26.445	0.000	-33.691895
27.090	0.000	-39.690674
27.735	0.000	-40.317741

.
. .
. .

x3p format

ISO standard ISO5436 – 2000

- ★ x3p is a container format, consisting of
 - ★ a binary surface matrix
 - ★ an xml file with meta information (specifications of the capturing device, operator information, data specific records)
- ★ Tools for working with x3p files: OpenFMC (C, Matlab)
Suite of R packages developed at CSAFE (x3ptools, bulletxtrctr)

Data collected at CSAFE

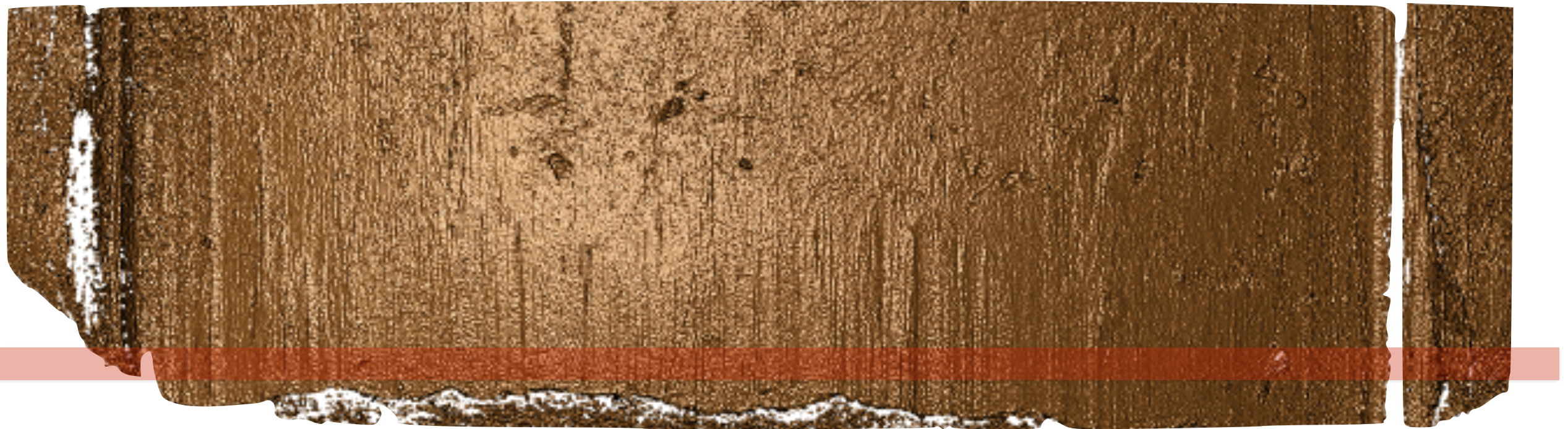
- ★ In collaboration with Forensic Labs and Police Departments
 - ★ Srinivasan Rathinam, LAPD:
4 bullets per barrel for 626 Beretta firearms
 - ★ Steve Kramer, St Louis PD:
2 SigSauer barrels with 192 fired bullets each
 - ★ Melissa McNally, Houston FSI:
test sets (6 kits with 25 bullets each),
persistence data shots 11-50 for eight Ruger barrels
 - ★ Hamby Sets 10, 36, 44, 224, and a clone (35 bullets each)
- ★ Total of > 40k scans of Land engraved areas

From raw scans to data for analysis

Statistical Analysis

Automatic matching score

Step 1: identify region suitable for matching



Region close to heel of bullet

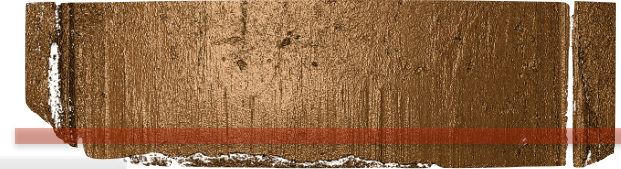
Avoid break-off

Statistical Analysis

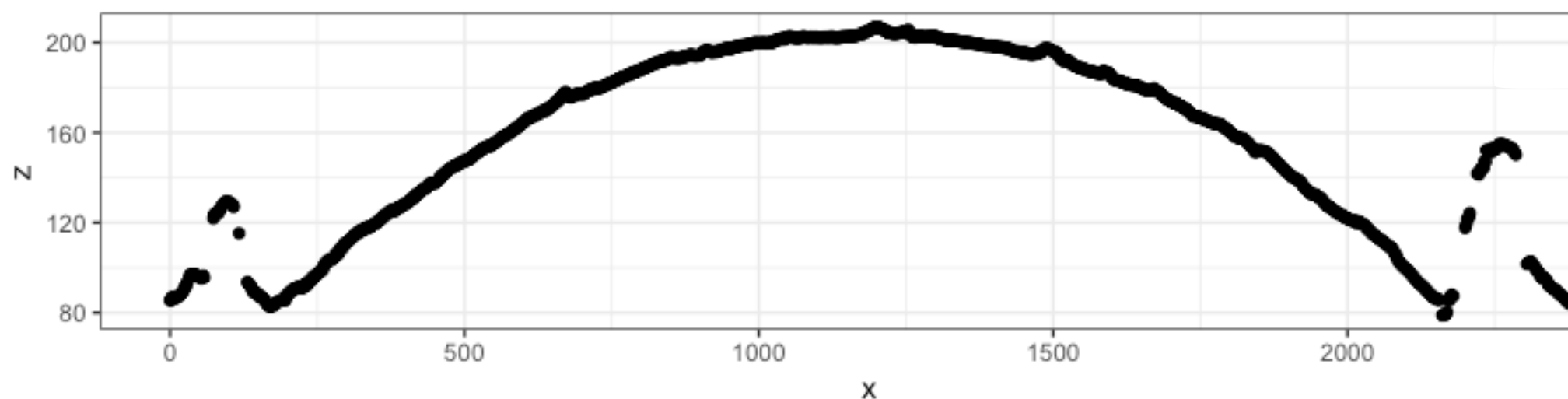
Automatic matching score

Step 1b: from scan to crosscut

Identify matching region



RGL device 3 [Focus]

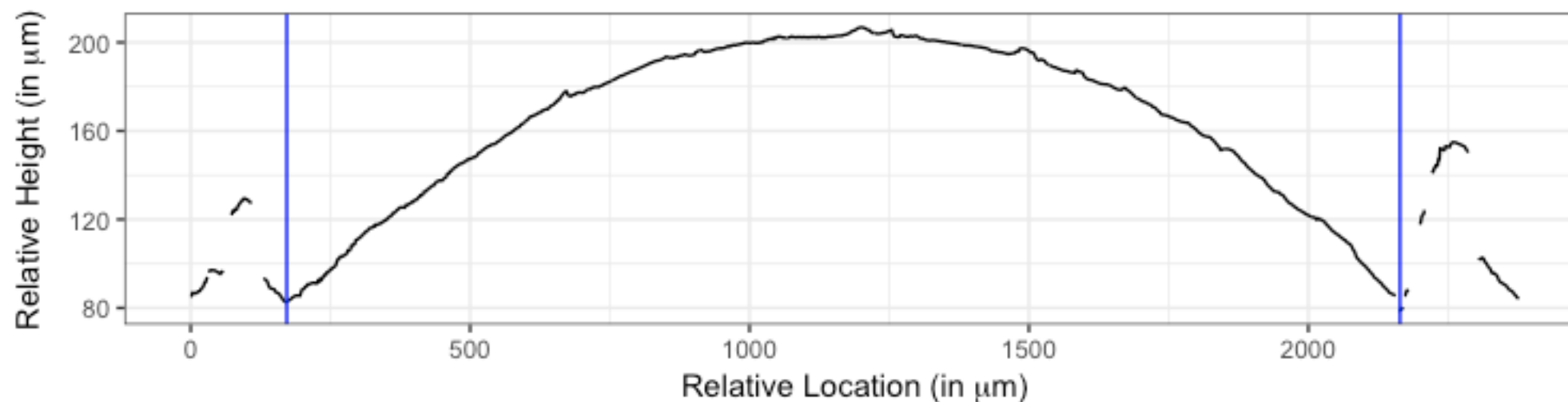
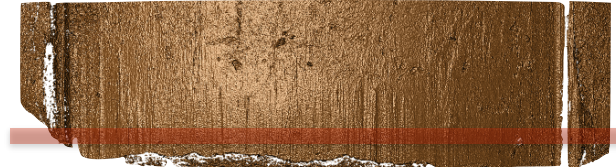


Statistical Analysis

Automatic matching score

Step 2: Identify groove locations

Identify matching region

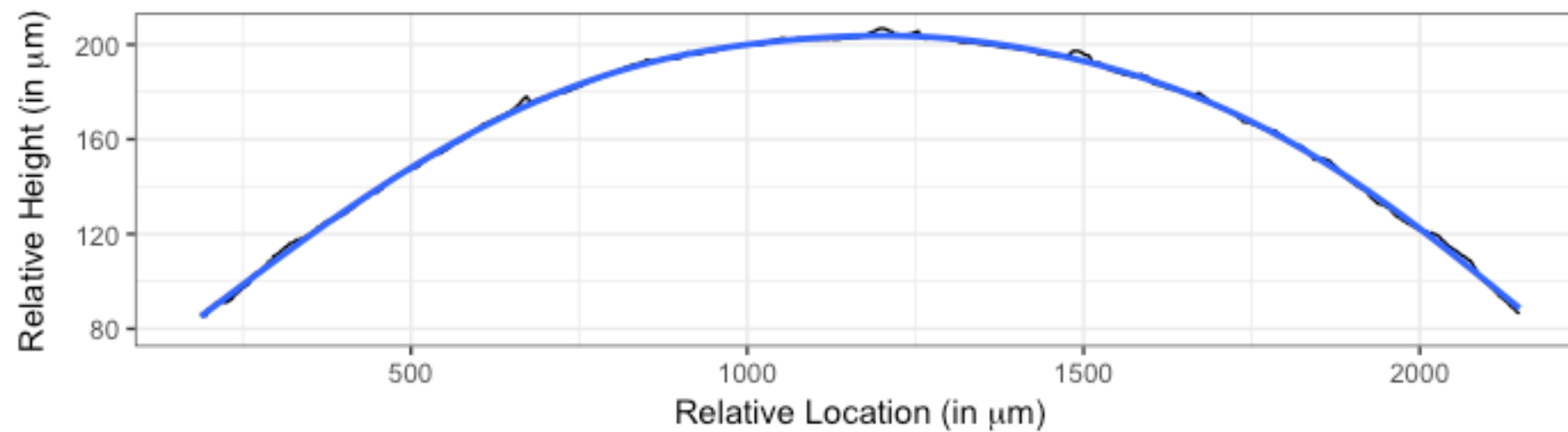


Shoulders (locations outside the grooves) are removed

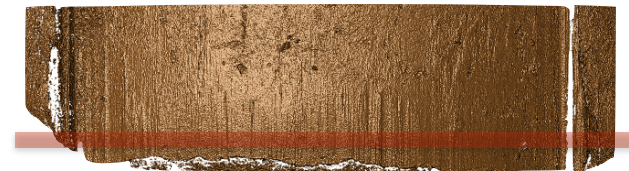
Statistical Analysis

Automatic matching score

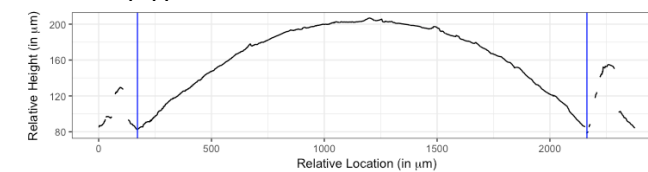
Step 3: Fit curvature



Identify matching region



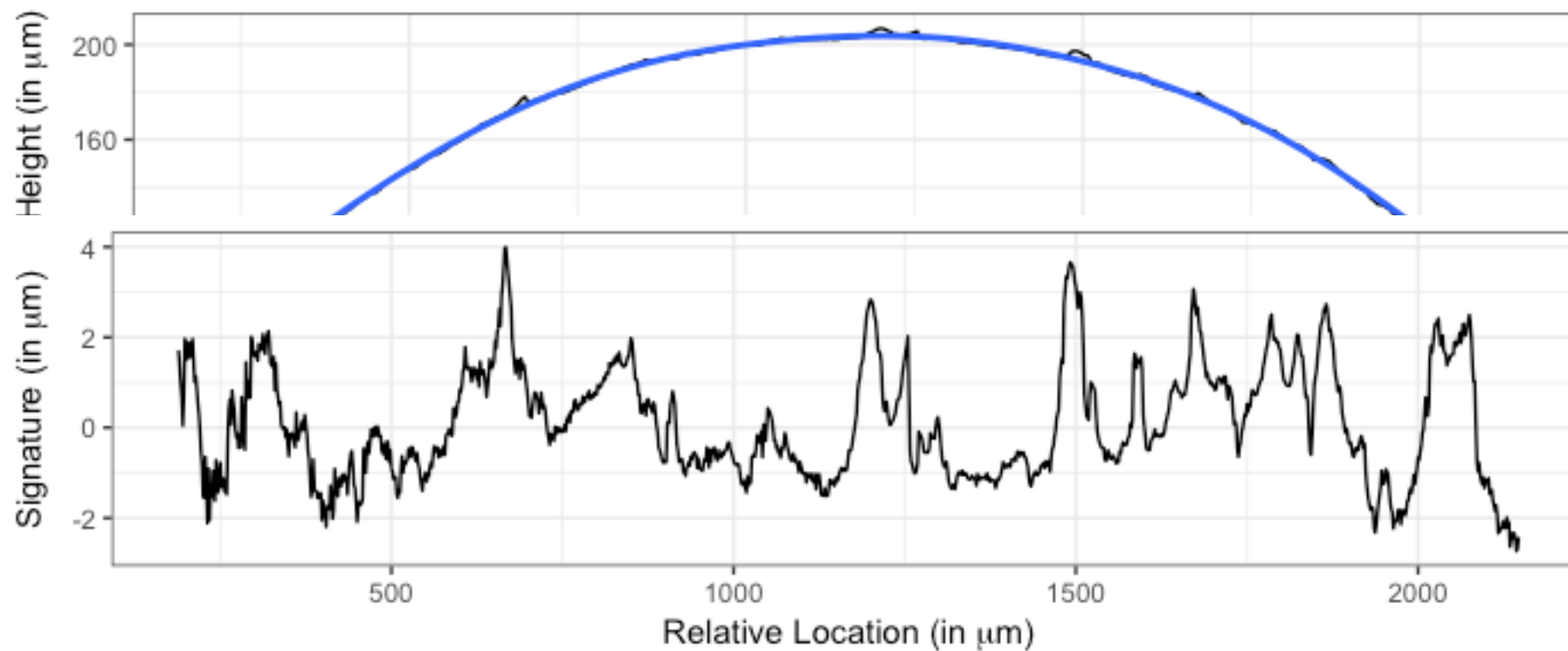
Identify groove locations



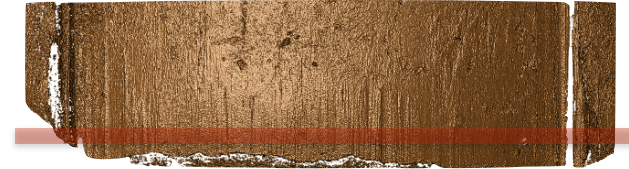
Statistical Analysis

Automatic matching score

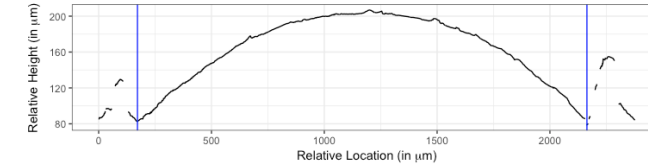
Step 3: Fit curvature & get signature



Identify matching region



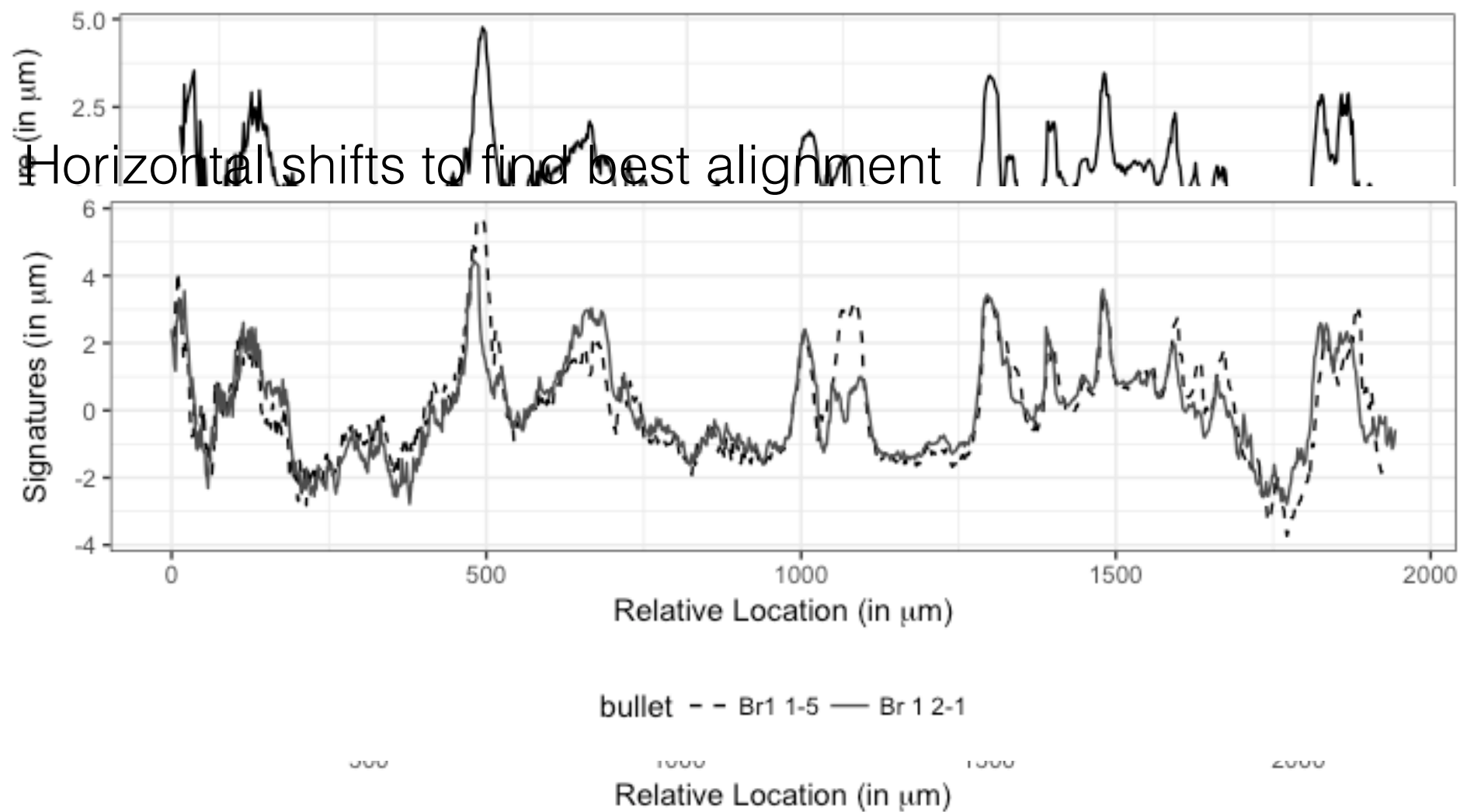
Identify groove locations



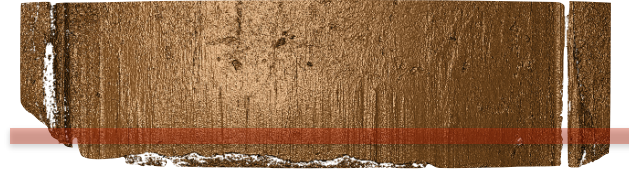
Statistical Analysis

Automatic matching score

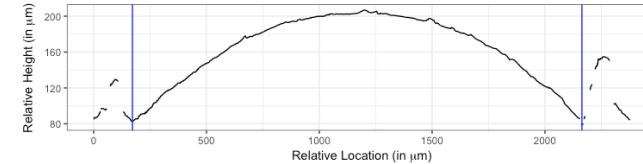
Step 4: Align signatures



Identify matching region



Identify groove locations



Extract signature



Statistical Analysis

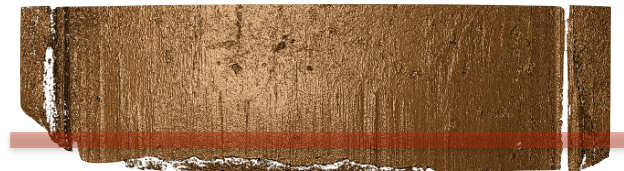
Automatic matching score

Step 5: Extract features

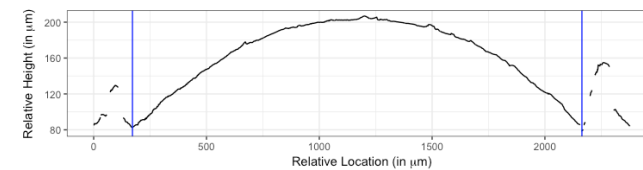
Feature should distinguish between a match and a non-match

- ★ # matches/mis-matches of peaks & valleys
- ★ # consecutive matches/mis-matches(cms)
- ★ depth of peaks/valleys
- ★ area between the signatures
- ★ cross-correlation function

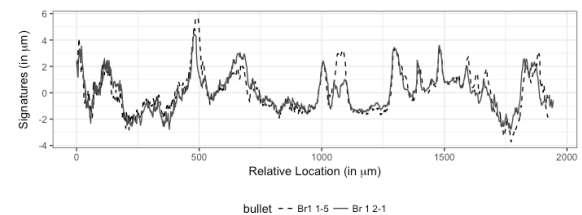
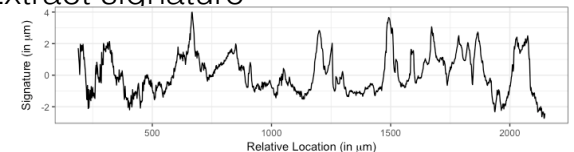
Identify matching region



Identify groove locations



Extract signature

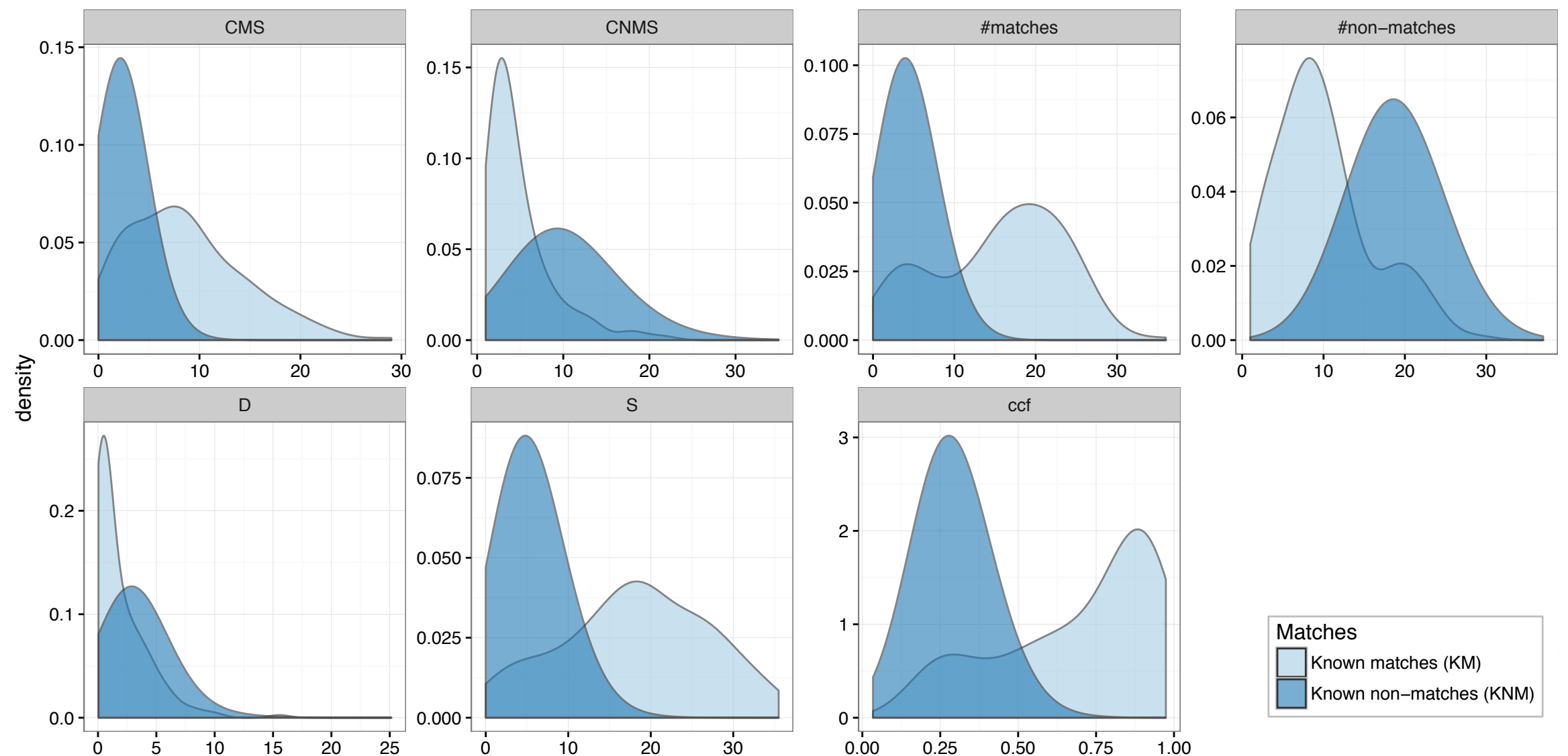


Features & comparisons

barrel1	bullet1	land1	barrel2	bullet2	land2	ccf	D	matches	mismatches	cms	non_cms	Known match
4	2	1	10	1	3	0.26	0.00	2.16	20.49	0.54	8.19	FALSE
4	2	1	2	1	2	0.30	0.00	2.31	19.41	0.58	8.25	FALSE
Unk	G	1	4	2	1	0.58	0.00	3.48	18.94	1.74	8.42	FALSE
4	1	3	4	2	1	0.85	0.00	6.14	16.41	2.23	4.24	TRUE
4	2	1	10	2	5	0.38	0.00	2.37	18.61	1.18	6.86	FALSE
4	2	1	6	2	6	0.32	0.00	4.01	16.43	2.29	4.98	FALSE
4	2	1	5	2	2	0.24	0.00	2.24	18.02	0.56	5.00	FALSE

Features & comparisons

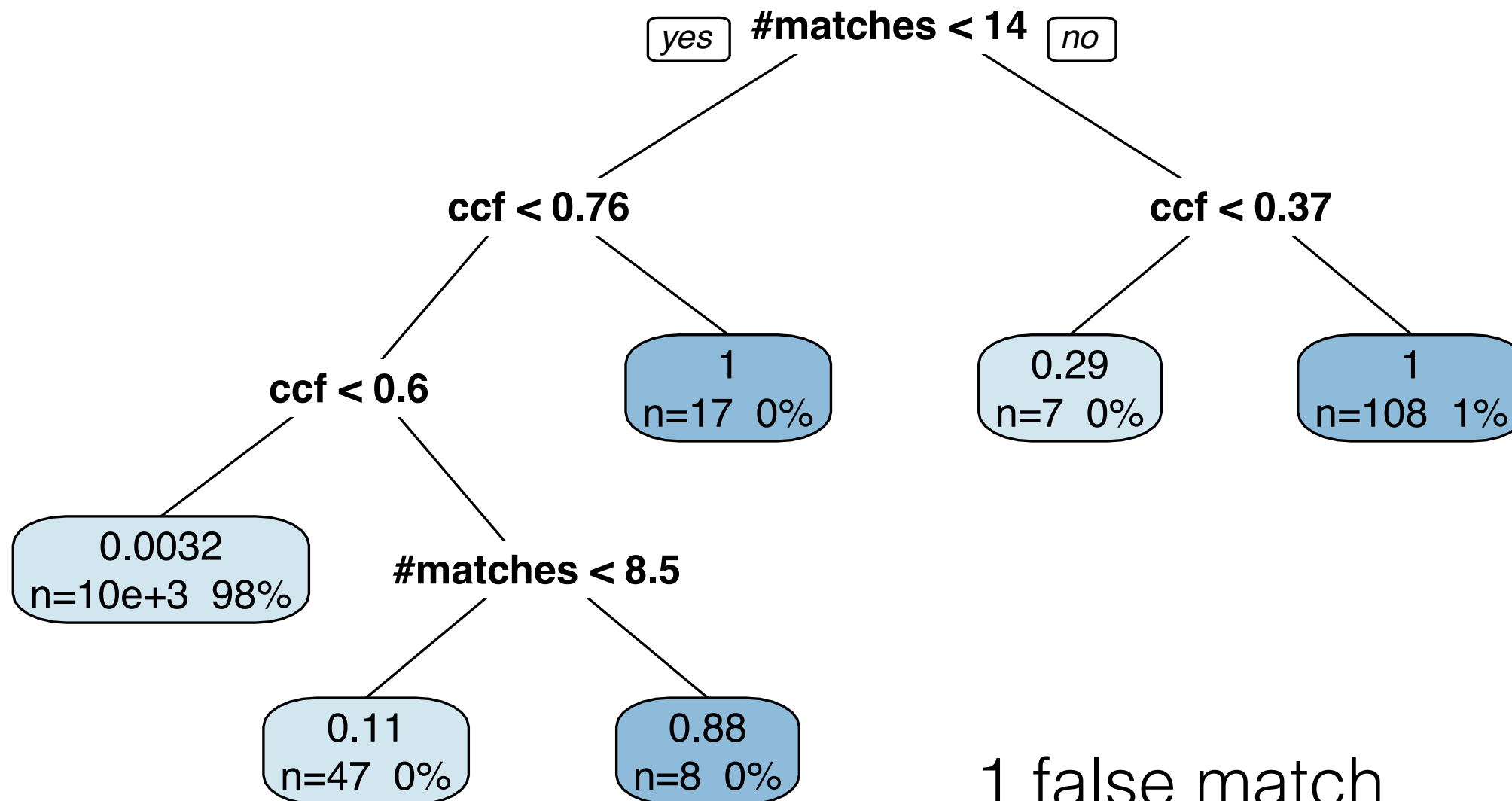
All features show distinction between known matches and known non-matches



Combining Features

Decision Tree

★ Decision Tree (1984 Breiman)

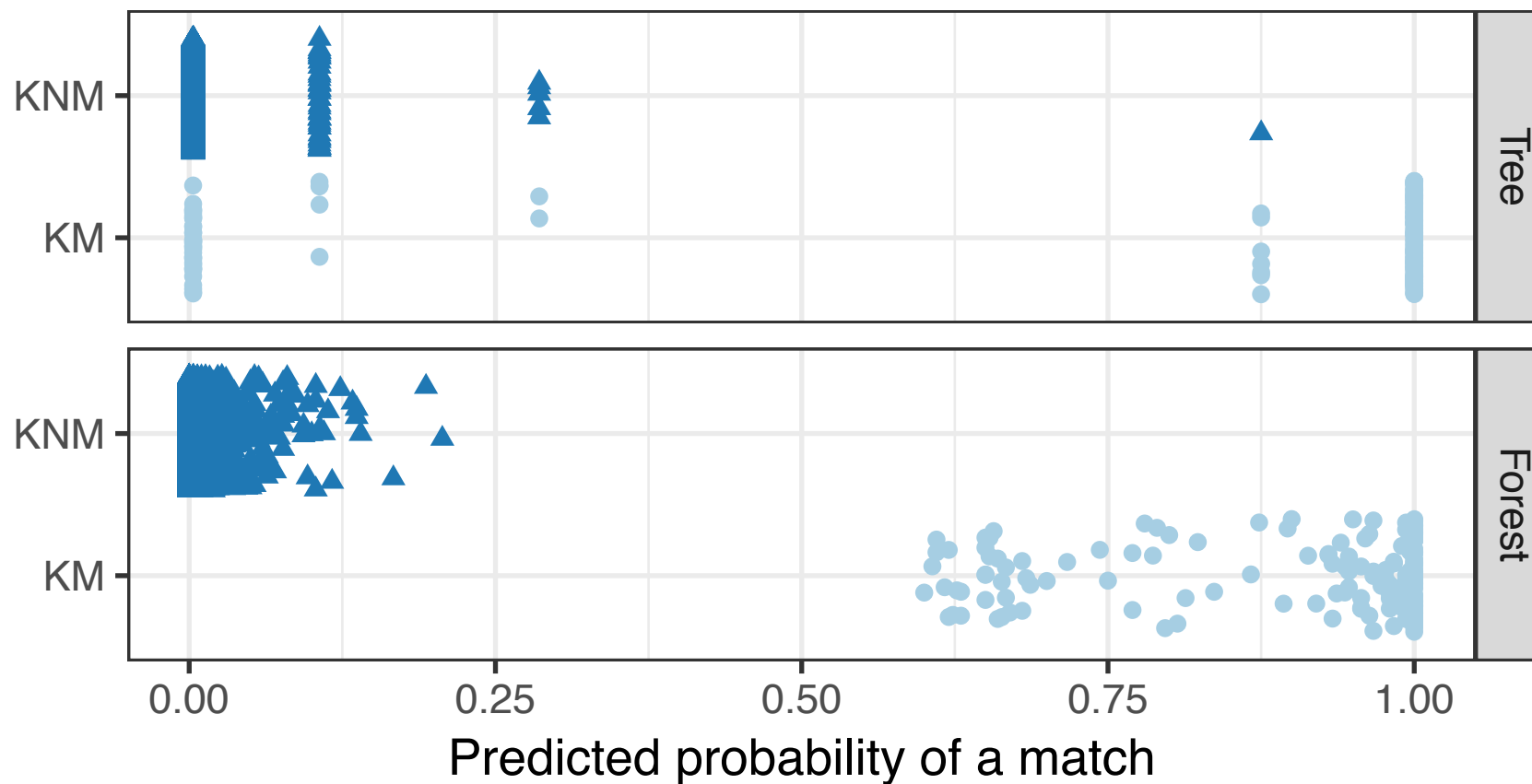


1 false match
24 missed matches

Combining Features

Random Forest

★ Combination of Decision Trees (500 trees)



*Automatic matching of
bullet land impressions,*
Annals of Applied
Statistics,
Eric Riemer Hare, Heike
Hofmann, and Alicia
Carriquiry

*Algorithmic approaches to
match degraded land
impressions*
Eric Hare; Heike Hofmann;
Alicia Carriquiry
Law, Probability and Risk,
Volume 16, Issue 4, 1
December 2017, 203–221,
<https://doi.org/10.1093/lpr/mgx018>

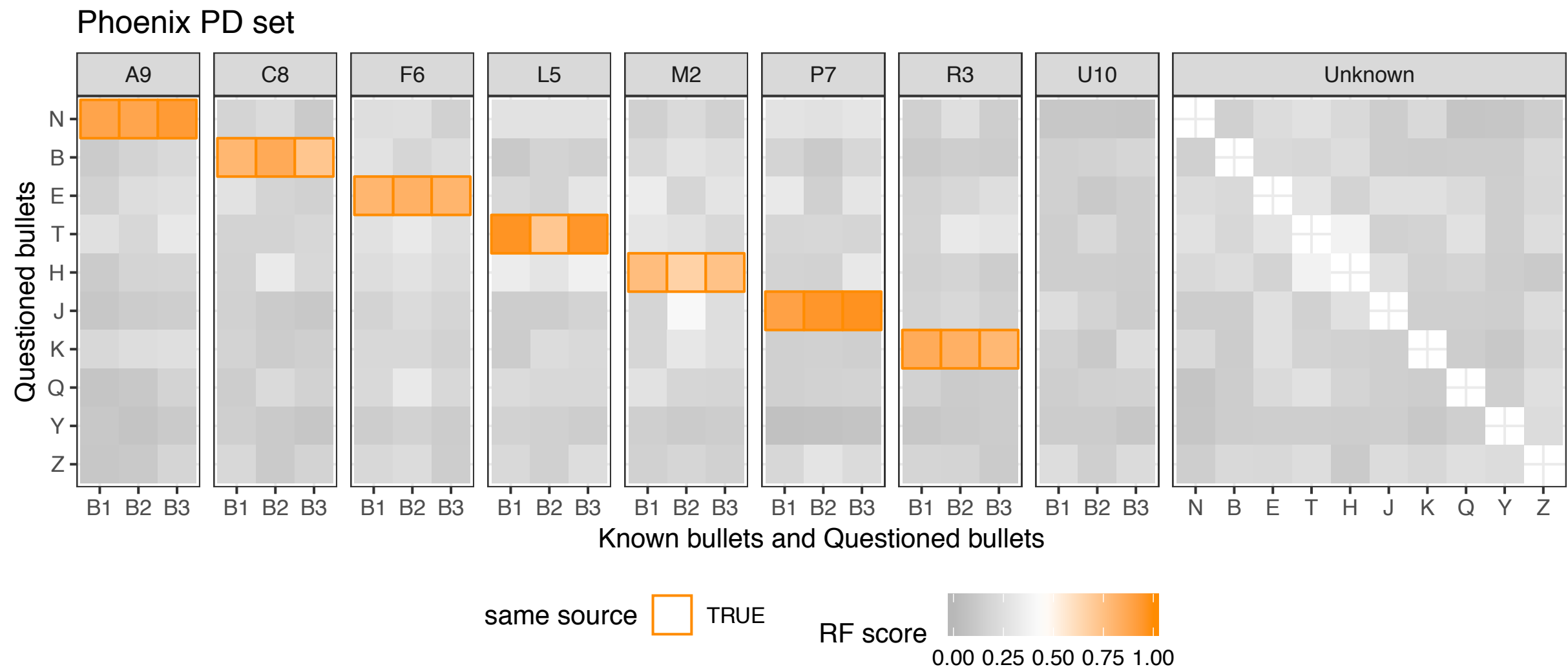
- ★ one false match (score too high) for tree, several false non-matches (scores too low)
- ★ no errors for Random Forest score, good separation

Case validation

Random Forest

★ Phoenix PD Study (Tyler Klep)

- ★ known matches: eight barrels with three test fires each
- ★ ten questioned bullets



Validating the RF score

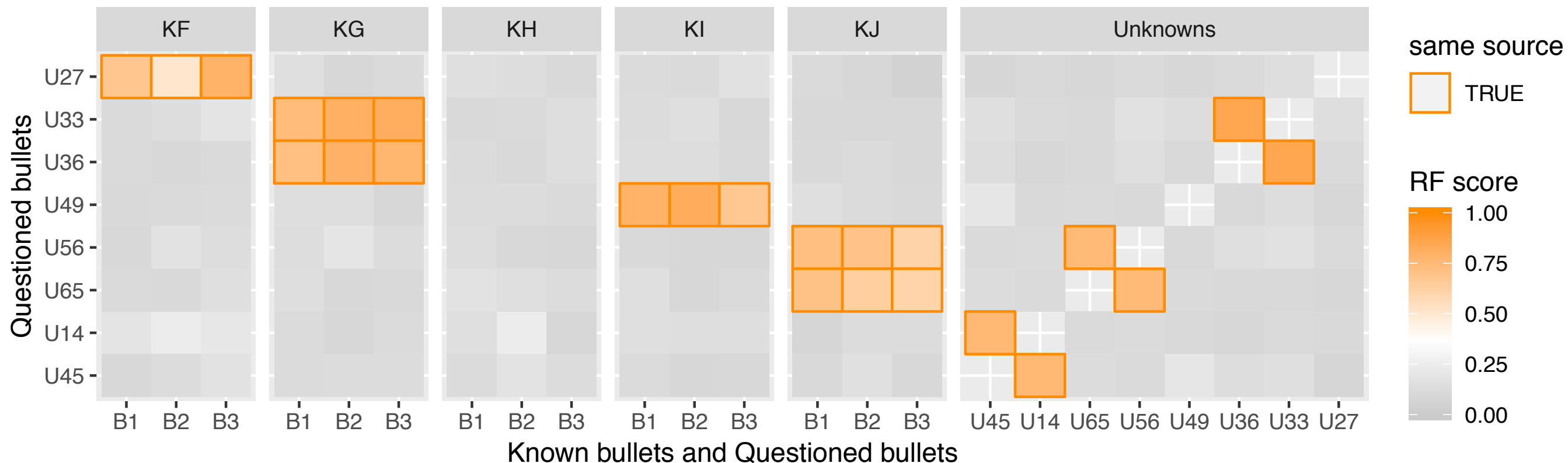
Random Forest

★ Houston Test 1 (Melissa McNally)

★ known matches: five barrels with three test fires each

★ eight questioned bullets

Houston set 3



Conclusions

- ★ Preliminary results are promising:
expansion to other firearm/ammunition combinations?
- ★ Rewarding to work on project with obvious high impact
- ★ Challenges at every step:
 - ★ data collection, data wrangling, feature extraction, modeling
 - ★ theoretical foundations, knowledge transfer to labs
 - ★ (computational) reproducibility

We need Openness

<https://github.com/CSAFE-ISU>

- ★ *open data*: e.g. NIST Ballistics Research Database
- ★ *open algorithms*: peer review, accountability
- ★ *open results*

Justice is only possible in a transparent process

Thank You!

Questions?

Heike Hofmann (hofmann@iastate.edu, @heike_hh)
ISU CSAFE bullet team

